CONCRETE PAVING Technology

Subgrades and Subbases for Concrete Pavements

Careful attention to the design and construction of subgrades and subbases is essential to ensure the structural capacity and ride quality of all types of pavements.

For concrete pavements, the requirements may vary considerably depending on subgrade soil type, environmental conditions, and amount of heavy truck traffic. In any case, the objective is to obtain a condition of uniform support for the pavement that will prevail throughout its service life. Methods for accomplishing this are described in this publication.

Subgrades—

The subgrade is the natural ground, graded and compacted, on which the pavement is built. Preparation of the subgrade includes:

1. Compacting soils at moisture contents and densities that will ensure uniform and stable pavement support.

2. Whenever possible, setting gradelines high enough and making side ditches deep enough to increase the distance between water table and pavement.

3. Crosshauling and mixing of soils to achieve uniform conditions in areas where there are abrupt horizontal changes in soil type.

4. Using selective grading in cut and fill areas to place the better soils nearer to the top of the final subgrade elevation.

5. Improving extremely poor soils by treatment with cement or lime, or importing better soils, whichever is more economical.

Subbases—

Under certain conditions, described in a later section, a subbase layer may be needed. In this publication, a subbase is defined as the layer of material that lies immediately below the concrete pavement. Some engineers call this a base course since that term is used to designate the first layer beneath an asphalt surface. However, a distinction in terminology needs to be made. The material quality requirements for a subbase are not as strict as those for a base since, under concrete, the pressures imposed on this layer due to vehicle loadings are much lower than those under asphalt.

Subbases may be constructed of granular materials, cement-treated materials, lean concrete, or open-graded, highly-permeable materials, which may be stabilized or unstabilized. For light traffic pavements such as residential streets, secondary roads, parking lots, and light-duty airports, the use of a subbase layer is not required, and the desired results can be obtained with proper subgrade preparation techniques.

When the use of a subbase is considered appropriate, the best results are obtained by:

1. Selecting subbase materials that meet minimum requirements for preventing mud-pumping of subgrade soils.

American Concrete Pavement Association

2. Specifying gradation controls that will ensure a reasonably constant subbase gradation for individual projects.

3. Specifying a minimum subbase depth of 4 in.

4. Specifying a minimum density for untreated subbases of 105 percent of AASHTO T99 for heavily traveled projects.

5. Specifying a cement-treated or lean concrete subbase that provides a strong and uniform support for the pavement and joints; provides an all-weather working platform; and contributes to smoother pavements by giving firm support to the forms or paver during construction.

6. Specifying a permeable subbase for pavements carrying high volumes of heavy trucks for which past experience indicates the potential for pavement faulting and pumping.

Uniform Support—

Consideration of the properties of concrete reveals that a single principle applies to every aspect of subbase and subgrade design. Concrete has a modulus of elasticity of 4 to 6 million psi and thus has a high degree of rigidity. Also, concrete for paving has substantial beam strength as indicated by its 28-day flexural strengths ranging from 550 to 750 psi, or even greater values for fast-track concretes. This rigidity and beam strength enable concrete pavements to distribute loads over large areas of the subgrades as shown in Fig. 1. As a result, deflections are small and pressures on the subgrade are very low.

Concrete pavements, therefore, do not require strong foundation support. It is much more important that the support be reasonably uniform with no abrupt changes in degree of support. This is in contrast with the principle of design for flexible pavements where successively stronger subbase and base layers are required to distribute the much higher pressures transmitted by wheel loads through an asphalt surface.

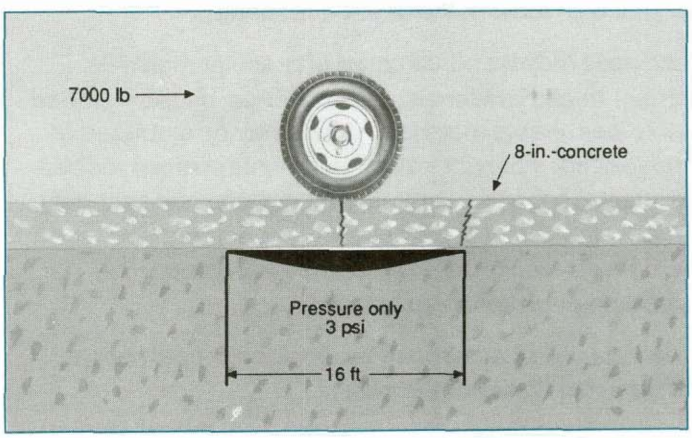

Figure. 1— Concrete distributes wheel loads over large areas and thus keeps subgrade pressures low.

The principle of uniform subgrade support explains pavement behavior that otherwise might be difficult to understand. Performance surveys have been made over many miles of old concrete pavements constructed without subgrade compaction control and without subbases. These old pavements were still in excellent condition where the subgrade was naturally uniform. Distress is limited to cut-fill transitions and other locations where there are abrupt changes in subgrade and moisture conditions.

Most highway pavements have subbases and were built with some degree of subgrade compaction control. Surveys show better performance on low-strength soils where construction methods provided reasonably uniform support than on stronger soils lacking uniformity.

SUBGRADE PRESSURES
12,000 lb. load on 12-in. plate (106 psi)

Loading position	Maximum subgrade pressure psi	Maximum subgrade pressure tons per square foot
1. Slab interior	3	0.22
2. Outside edge	6	0.43
3. Outside corner	7	0.50
4. Transverse joint edge	4	0.28

The diameter of load distribution area was 20 + ft.

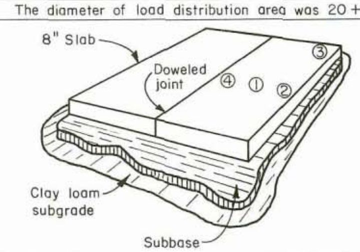

Figure. 2— Subgrade pressures for a 12,000-lb. load applied at several positions on slab.

Tests[1] made by the Portland Cement Association show that heavier loads are distributed over large areas of the subgrade and do not cause high subgrade pressures. Fig. 2 gives test conditions and subgrade pressures for a 12,000-lb load. The applied pressure of 106 psi was reduced to subgrade pressures of only 3 to 7 psi by distribution of the applied load over more than 20 ft. Other studies[2-4] also show that the pressures are quite low, considerably less than the bearing strengths of the subgrade.

Design for Uniform Support—

To design a subgrade and a subbase that provide reasonably uniform support, the three major causes of nonuniformity must be controlled: (1) expansive soils, (2) frost heave, and (3) mud-pumping.

Effective control of expansive soils and frost heave is most economically achieved through appropriate subgrade preparation techniques. In cases where the potential for mud-pumping exists, a thin subbase layer is required. The use of thick subbase layers for substantial control of expansive soils and frost heave is not as effective as subgrade work and usually costs more. Further discussion of these factors will be found in the sections following.

Subgrades

Where subgrade conditions are not reasonably uniform, correction is most economically and effectively achieved by proper subgrade preparation techniques, such as selective grading, crosshauling, mixing at abrupt transitions, and moisture-density control of subgrade compaction. Particular attention is needed for the control of expansive soils and excessive differential frost heave.

A subbase layer also helps provide uniform support, but its primary purpose is to prevent mud-pumping. Whether or not a subbase is required, proper subgrade preparation is the best means of obtaining uniform support.

Expansive Soils—

Excessive differential shrink and swell of expansive soils cause nonuniform subgrade support. As a result, concrete pavements may become distorted enough to impair riding quality. Several conditions can lead to this pavement distortion and warping:

1. If expansive soils are compacted when too dry or are allowed to dry out prior to paving, subsequent expansion may cause high joints and loss of crown.
2. When concrete pavements are placed on expansive soils with widely varying moisture contents, subsequent shrink and swell may cause bumps, depressions, or waves in the pavement.
3. Similar waves may occur where there are abrupt changes in the volume-change capacities of subgrade soils .

Identification of Expansive Soils—
Knowledge of the volume-change potential of soils and the resulting effects on pavement performance has been gained through experience and research. Simple tests provide indices that serve as useful guides to identify approximate volume-change potential of soils.[6,7] For example, Table 1 shows approximate relationships.

(Note that in Table 1, the percent expansion is from a dry to a saturated condition. In reality, much less expansion would occur because these extremes of moisture variation would not take place.)

Experience has shown that the volume changes of clays with a medium or low degree of expansion usually cause no problems for concrete pavements, especially if abrupt nonuniformities of soil conditions are minimized by subgrade grading operations.

Table 1— **Relation of soil index properties and probable volume changes for highly plastic soils**

Data from index tests [1]			Estimation of probable expansion, [2] percent total volume change (dry to saturated condition)	Degree of expansion
Colloid content (percent minus 0.001 mm.) (ASTM D422)	Plasticity index (ASTM D4318)	Shrinkage limit, percent (ASTM D427)		
>28	>35	<11	>30	Very high
20-31	25-41	7-12	20-30	High
13-23	15-28	10-16	10-20	Medium
<15	<18	>15	<10	Low

Adapted from Reference 5

[1] *All three index tests should be considered in estimating expansive properties.*

[2] *Based on a vertical loading of 1.0 psi. For higher loadings the amount of expansion is reduced, depending on the load and on the clay characteristics.*

Certain expansion test procedures such as AASHTO T116 (ASTM DI883) and ASTM D4546, D4829, CALTRANS test method No. 354[8] and soil suction tests (ASTM D3152 and References 9-11) are especially suitable for evaluating the volume change of subgrade soils. Some of the important factors determined by these tests, which are not indicated by simple index tests, are:

- The effect of compaction moisture and density on soil swell characteristics.
- The effect of surcharge loads.
- The expansion for the total sample gradation rather than only for a finer gradation fraction of the soil.

Most soils sufficiently expansive to cause pavement distortion are in the AASHTO A-6 or A-7 groups. By the Unified Soil Classification System, soils classified as CH, MH, and OH are considered expansive.

Control of Expansive Soils—
The amount of volume change that will occur with a given expansive soil depends on several factors:

1. Climate—degree of moisture change that will take place in the subgrade throughout the year or from year to year. It is generally true that placement of a pavement will reduce the degree of moisture change in the underlying subgrade.
2. Load conditions—surcharge effect of the weight of soil, subbase, and pavement above the expansive soil.
3. Moisture and density conditions of the expansive subgrade at the time of paving.

Knowledge of the interrelationship of these factors leads to the selection of economical control methods.

Subgrade Grading Operations— Tests[12] indicate that soil swell can be reduced by surcharge loads. Field measurements show that excessive swell at depths of 1 to 2 ft gradually decreases to a negligible amount at depths of 15 ft or more. Thus, excessive swell can be controlled by placing the more expansive soils in the lower parts of the embankments and crosshauling less expansive soils for the upper part of the subgrade in both embankments and excavations. Selective grading and mixing of soils provide reasonably uniform conditions in the upper part of the subgrade and gradual transitions between soils with varying volume change properties. These operations are also used at cut-fill transitions to correct abrupt changes in soil type.

In deep-cut sections of highly expansive soils, considerable expansion may occur due to the removal of the natural surcharge load and the consequent absorption of additional moisture. Since this expansion takes place slowly, it is essential to excavate these deep cuts well in advance of other grading work.

Compaction and Moisture Control— Volume changes are further reduced by adequate moisture and density controls during compaction. To reduce volume changes, it is critical to compact highly expansive soils at 1 to 3 percent above optimum moisture, AASHTO T99. Where embankments are of considerable height, compaction moisture contents can be increased from slightly below optimum in the lower part of the embankment to above optimum in the top 1 to 3 ft.

Research[13-16] verifies that expansion is greatly reduced for most plastic soils when compacted at moisture contents exceeding AASHTO T99 optimum.

Fig. 3 shows the strong influence of compaction moisture and density on volume change. Lower compactive effort will result in considerably less expansion, but this is not recommended in practice. At lower compactive efforts there may be practical difficulties in obtaining a reasonably uniform degree of compaction. Consequently, this is best achieved by increased moisture content with compactive efforts close to that of AASHTO T99.

Laboratory research[16,17] has shown that expansive soils compacted slightly wet of optimum expand less but have higher strengths after wetting and absorb less water.

The U.S. Army Corps of Engineers and other agencies use a modified moisture-density test, AASHTO T180, with a higher compaction effort that gives higher densities and lower optimum moisture contents than the usual test method, AASHTO T99. Fig. 4 compares moisture-density relationships for the two test procedures for an expansive

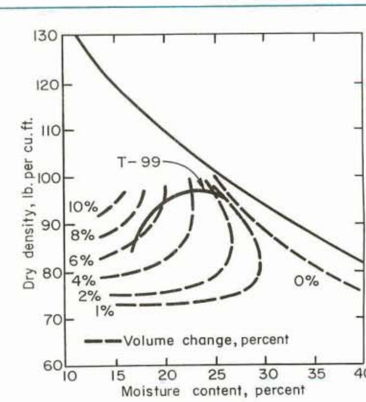

Figure 3.— Volume changes for different compaction conditions.

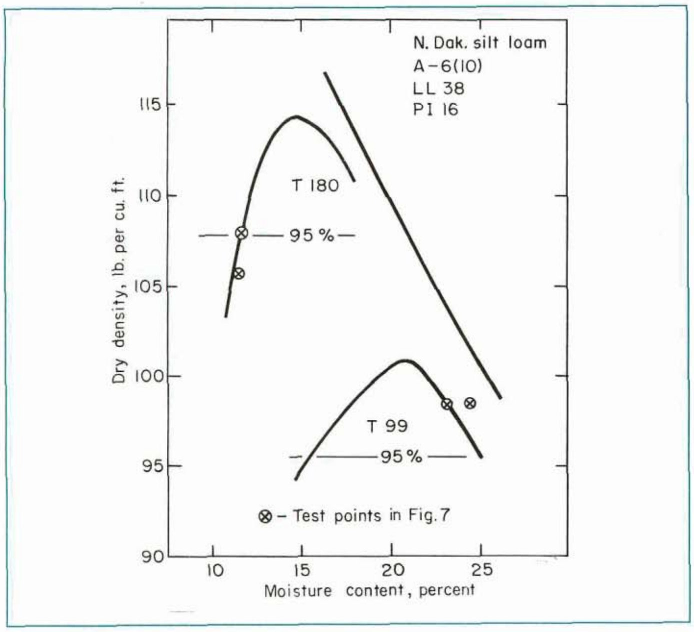

Fig. 4.—Moisture-density curves for a typical expansive soil.

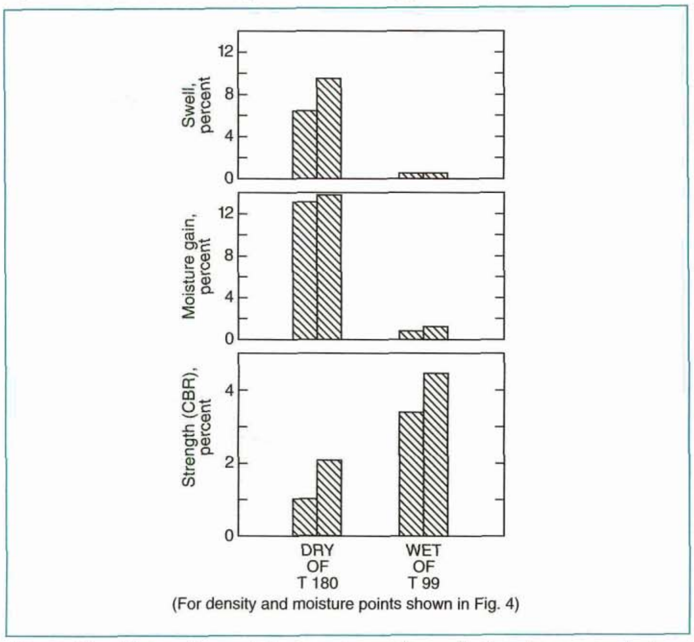

Figure 5.—Strength, moisture gain, and swell of soil compacted dry of AASHTO T180 and wet of AASHTO T99 optimum moisture.

A-6 soil. The modified test was developed to represent higher compaction of granular subbases and base courses. It is also useful for subgrades of low plasticity. While excellent for these purposes, the higher compactive effort results in moisture contents that are much too low for expansive soils. Compaction of expansive soils at these lower optimum moisture contents results in excessive swell, which in turn causes rough riding pavements.

To illustrate, Fig. 5 shows that expansion for an A-6 soil is greatly reduced when it is compacted wet of AASHTO T99 optimum, compared to the high expansion obtained when compacted dry of AASHTO T180 optimum with the greater compactive effort. The data also show that greater strengths and lower moisture absorptions prevail, after soaking, for soil compacted wet of AASHTO T99.

Field experience[17,18] also shows the best compaction moisture content to use with expansive soils. Objectionable distortions have not occurred in pavements placed on uniform plastic soils with moisture contents near the plastic limit (slightly greater than AASHTO T99 optimum). On the other hand, warping has occurred for pavements placed on expansive subgrades of lower moisture contents. Experience also demonstrates that subgrades compacted slightly wet offer greater resistance to water gain by absorption or water loss by evaporation than do soils compacted under any other condition.

After pavements are placed in service, most subgrades reach a moisture content approaching their plastic limit, which is slightly above the standard optimum. When this moisture content is obtained during construction, the subsequent changes in moisture will be much less, and the subgrade will retain the reasonably uniform stability needed for good pavement performance.

It is also essential to keep the subgrade from drying out before placing the subbase layer or pavement. If expansive soils do dry out, they should be recompacted at the required moisture content just before placing the subbase course or pavement. The depth of subgrade needing reprocessing can be determined from field moisture tests.

In summary, experience and research confirm that compaction of plastic soils at moisture contents above standard optimum reduces expansion potential, provides more stable subgrades, and minimizes the degree of moisture change after the pavements are placed in service. As a result, more uniform support is provided, and volume changes are kept to a minimum under service conditions.

Nonexpansive Cove — In areas with prolonged periods of dry weather, highly expansive subgrades may require a cover layer of low-volume-change soil placed full width over the subgrade. This will minimize changes in the moisture content of the underlying expansive soil and will also have some surcharge effect. A low-volume change layer with low permeability is not only more effective but usually less costly than a permeable, granular soil. Permeable materials are not placed directly on top of expansive soils since they permit greater changes in subgrade moisture content.

Where conditions conducive to mud-pumping exist, that portion of the low-volume-change layer immediately below the pavement should be designed to prevent mud-pumping. (See section on mud-pumping.) If the depth of the nonexpansive layer is greater than 6 in., the more

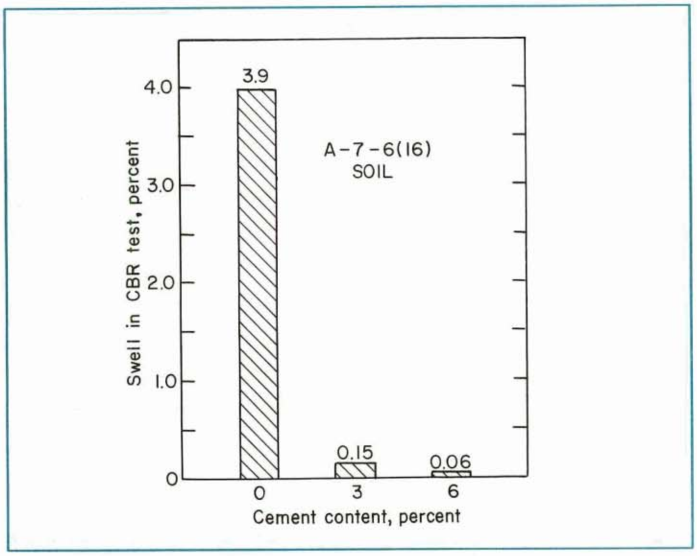

Figure 6.— Effect of cement treatment on expansive clay.

exacting criteria for nonpumping subbases are not required for the lower portion more than 4 to 6 in. below the pavement. Less costly, low-volume-change soils from regular excavation or nearby borrow may be used.

Cement- and Lime-Modified Subgrades— If the supply of suitable soils for nonexpansive cover is limited, it may be more economical to modify existing soils with cement or lime, which greatly reduces their expansive properties.

For cement-modification, laboratory tests and experimental projects[19,20] have shown the effectiveness of the treatment. An example of test results on a cement-modified clay is shown in Fig. 6.

For specific projects, the additive contents for control of volume change are selected on the basis of laboratory test results.* Often, simple index tests such as the plasticity index and shrinkage limit are used as measures of the effectiveness of the treatment. A comparison[21] of the effects of cement and lime modification are given in Table 2.

If conditions leading to mud-pumping exist (see section on mud-pumping), a nonpumping subbase 4 to 6 in. thick should be placed over the modified subgrade.

Special Methods— Where the potential exists for severe soil volume changes, several special treatments have been used with success. These include ponding (preswelling),[22-25] membrane encapsulation,[26] horizontal geomembranes,[27,28] and vertical moisture barriers.[29-31] Electro-osmotic chemical stabilization and pressure injection of chemicals have been used with mixed results.[32,33] Information on these specialized treatments is beyond the scope of this publication; details of the techniques are given in the cited references.

* A discussion of cement-modified soils and test methods is given in *Soil-Cement Laboratory Handbook*, published by the Portland Cement Association.

Table 2— ***Effect of cement and lime treatment on properties of clay soils***

Soil No.	Additive	Shrinkage Limit, percent	Plasticity Index	28-day Compressive Strength, psi
1	none	13	30	—
	3% cement	24	13	135
	3% lime	27	10	128
	5% cement	30	12	233
	5% lime	29	10	190
7	none	13	36	—
	3% cement	26	21	149
	3% lime	30	17	97
	5% cement	32	17	232
	5% lime	34	14	164
10	none	14	43	—
	3% cement	24	24	186
	3% lime	25	25	234
	5% cement	31	16	377
	5% lime	30	17	292

Additional data on a total of 11 clay soils is given in Reference 21.

Frost Action—

For pavement design purposes, frost action can be evaluated by the effects of (1) frost heave and (2) subgrade softening on spring thawing. Design considerations for controlling frost heave are not necessarily identical to those for controlling subgrade softening. For example, a soil with high frost-heave potential will not necessarily exhibit the maximum degree of subgrade softening. Even though both factors are in operation, it is important to recognize how each, taken separately, has affected the performance of pavements in service.

Uniquely, field experience with concrete pavements has shown that frost action damage due to inadequate design is a result of the first factor, frost heave, in the form of abrupt, differential heave. The second factor, subgrade softening, is not a design consideration for concrete pavements since strong subgrade support is not required.* Design for concrete is concerned with reducing the nonuniformity of subgrade soil and the moisture conditions that lead to objectionable differential heave—especially where subgrade soils vary abruptly from nonfrost-susceptible sands to the highly frost-susceptible silts at cut-fill transitions or at silt pockets; where groundwater is close to the surface; or where water-bearing strata are encountered.

The effects and mechanisms of frost action and related pavement design practices are fully discussed in References 34, 35, and 36.

Frost Heave—

For frost heave to occur, all of three conditions must be present: (1) frost-susceptible soil, (2) freezing temperatures penetrating the subgrade, and (3) a supply of water. (Some agencies consider that frost action will usually not be a problem if the water table is more than 10 ft below the surface).[32] With the absence of any one of these factors, frost heave will not occur .

Expansion of soil water on freezing is not sufficient to account for the degree of vertical heaving. Heaving is caused by a growth of ice lenses in the soil. When freezing temperatures penetrate a subgrade soil, water from the unfrozen portion of the subgrade is attracted to the frozen zone. If the soil is susceptible to capillary action, the water moves to ice crystals initially formed and freezes. If a supply of water is available, ice crystals will continue to grow, forming ice lenses of appreciable thickness that lift or heave the overlying pavement. If the rate of frost penetration into the subgrade is slow, thicker ice lenses will be developed since there is more time for water flow from the unfrozen zone.

Frost-Susceptible Soils—

Criteria and soil classifications for identifying frost-susceptible soils[34-38] usually reflect susceptibility to softening on thaw as well as to heaving. For concrete, the major concern is to reduce heaving, especially differential heaving. Control of spring softening is not a consideration for concrete pavement. Thus, as far as possible, differentiation should be made in classifications between soils susceptible to heave and those susceptible to thaw softening.

This is illustrated by a quote from Frost Action in Roads and Airports, Highway Research Board Special Report No. 1[37]: "...criteria for nonfrost susceptibility as they pertain to intense differential heaving need not lie identical to criteria pertinent to load-carrying capacity during the thaw period. Accordingly, the reader is asked to distinguish between adequacy of designs based on needs."

There is a wide diversity in frost susceptibility determination methods; almost all of the methods are unique for individual state, provincial, and federal agencies. Most of the methods are based on soil particle size determination, and several have criteria similar to that of Casagrande[39] — more than 3 percent smaller than 0.02 mm in non-uniformly graded soils. However, these methods seldom differentiate between frost heave and thaw softening. One method that makes this differentiation is the freeze-thaw test of the U.S. Army Corps of Engineers,[40] but the test and equipment are not simple.

In a general way, the degree of frost susceptibility can be explained by the hydraulic properties of soils: (1) capillarity or suction—the soil's ability to pull moisture by capillary forces, and (2) permeability—the soil's ability to transmit water through its voids. The relation of these properties to frost susceptibility is visualized in Fig. 7. The worst heaving usually occurs in fine-grained soils subject to capillary action. Low-plasticity, fine-grained soils with a high percentage of silt-size particles (0.05 mm to 0.005 mm) are particularly susceptible to frost heave. These soils have pore sizes small enough to develop capillary potential but large enough to permit travel of water to the frozen zone. Coarser soils could accommodate higher rates of flow but do not have the capillary potential to lift enough moisture for heaving. More cohesive soils,

* In some cases of older concrete pavements designed without consideration for the prevention of mud-pumping, spring subgrade softening has aggravated the pumping conditions. Correction for this properly falls in the category of subbase design to prevent pumping (see section on subbases) rather than as a frost-action design consideration.

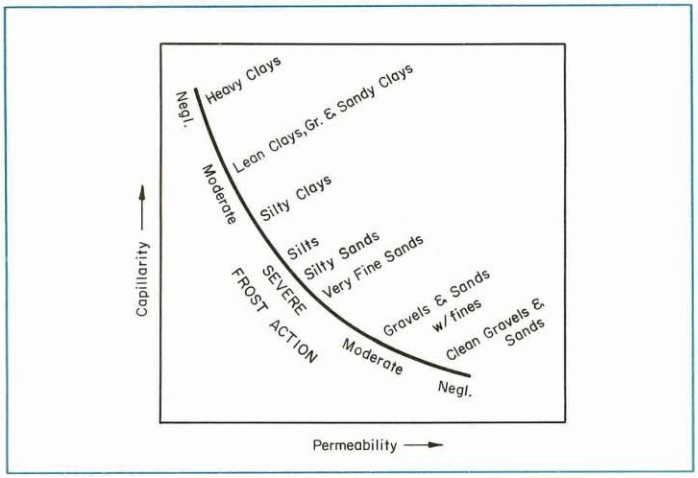

Figure 7.—The relation between frost action and hydraulic properties of soils.

although developing high capillarity, have low permeability, and water moves too slowly for growth of thick ice lenses. Frost heave studies[41] show that cohesive clay subgrades seldom develop detrimental heaving. These studies also show that low plasticity silts are most susceptible to frost heave, followed by loams and very fine sands, sandy loams, clay loams, and clays in decreasing order.

Spring Subgrade Softening—
Except in permafrost regions, a frozen subgrade thaws both from the surface downward and from the bottom upward. As a result, thawing is usually more rapid than

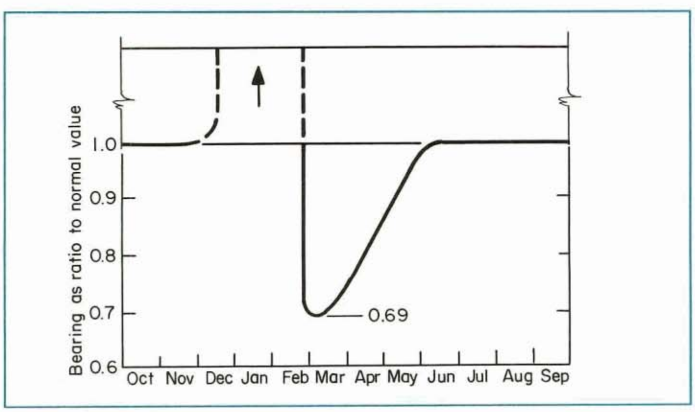

Figure 8.— Typical loss in bearing value on thaw.

freezing. When thawing starts, the moisture content of the subgrade may be high due to the previous moisture increase during freezing and to surface water infiltration. This water in the upper thawed layer cannot drain downward because of the frozen zone below. In addition, expansion has caused a loss in density. Under these conditions, there is a sharp reduction in subgrade support during the thaw period. Studies by the Motl Committee of the Highway Research Board show that the period of greatest strength loss is brief—usually two to three weeks—followed by a period of recovery after thawing is completed. Fig. 8 shows a typical loss of subgrade strength on thawing.

The periods of reduced subgrade support that accompany thawing have very little effect on concrete pavements. This is because concrete reduces pressures to safe limits by distributing loads over large areas and because concrete pavements are designed for fatigue stresses due to load repetitions. Fatigue effects during the period of reduced subgrade strength are offset by reduced fatigue during the longer period that the subgrade is frozen and offers very high support.

Concrete pavements designed on the basis of normal weather subgrade strengths have ample reserve capacity for the periods of reduced support during spring thaw. Tests on concrete airfield and highway pavements in frost areas show maximum reductions in subgrade support of 25 to 45 percent during the spring thaw periods. When these reduced values are used in design analyses, the results show that additional pavement thickness is not required. When the subgrade is frozen to a depth of 30 in. or more, subgrade support is so high that stresses in the concrete are not sufficient to cause fatigue consumption. Thus, the longer period of high support during freeze more than offsets the brief period of reduced support on thaw. Because of their reserve load carrying capacity, concrete pavements are exempted from load restrictions during periods of spring thaw.

Further evidence that concrete pavements designed with uniform support are not influenced by spring thaw is shown by the results of the AASHO* Road Test.[42] The pavement performance and the equations written to relate the design variables show that concrete pavements, with or without a subbase, were not affected by the spring thaw periods.

Thus field experience and design analyses verify that subgrade softening is not a factor in design considerations for the control of frost action for concrete pavements. It is the abrupt, differential frost heave that must be controlled.

Control of Heave—
The performance of older concrete pavements in frost-affected areas under today's increased traffic shows that extensive, costly controls are not needed to prevent frost damage. Surveys of these pavements indicate that control is needed only to reduce excessive heave and,

* At the time this test was conducted, the sponsor was the American Association of State Highway Officals (AASHO). Since then, the organization name was modified to the American Association of State Highway and Transportation Officials (AASHTO).

more critically, prevent differential heave by achieving reasonably uniform subgrade conditions. As in the case of expansive soils, a large degree of frost-heave control is attained most economically by appropriate grading operations and by controlling subgrade compaction and moisture.

Grade and Water Table Elevation— Grade lines are set high enough and side ditches constructed deep enough so that highly frost-susceptible soils are above the capillary range of groundwater tables. If possible, where groundwater is near the surface, the grade is kept 4 or 5 ft above ditch bottom in cuts and natural ground in fills.

Selective Grading and Mixing— Highly frost-susceptible soils are placed in the lower portions of embankments, and less susceptible soils are crosshauled to form the upper portion of the subgrade. Crosshauling and mixing are also used at cut-fill transitions to correct abrupt changes in soil type. Dimensions and details of transitions at cut-fill sections and at culverts are given in References 35 and 36.

Where soils vary widely or frequently in texture, mixing them is effective in preventing differential frost heave. With modern construction equipment, the mixing of nonuniform soils to form a uniform subgrade is often more economical than importing select materials from borrow pits.

Removal of Silt Pockets— Where highly frost-susceptible soils are pocketed in less susceptible soils, they are excavated and backfilled with soils like those surrounding the pocket. Moisture and density conditions of the replacement soil should be as similar as possible to those of the adjacent soils. At the edges of the pocket, the replacement soil is mixed with the surrounding soil to form a tapered transition zone, just as in cut-fill transitions.

Compaction and Moisture Control— After reasonable uniformity has been achieved through grading, additional uniformity is obtained by proper subgrade compaction at controlled moisture contents. The permeability of most fine-grained soils is substantially reduced when they are compacted slightly wet of AASHTO T99 optimum moisture. Reducing soil permeability retards the rate of moisture flow to the frozen zone and consequently reduces frost heaving. Research[43,44] confirms that less frost heave occurs at the wetter condition.

Furthermore, compaction at these moisture contents makes subgrades less susceptible to nonuniform moisture changes (changes due to saturation and drying) at the pavement edges and under the joints.

Experience shows that after a few seasons in service, subgrade moistures will naturally increase to slightly above optimum for frost-susceptible soils in the climates where frost action is a problem. Better conditions of soil structure, permeability, and resistance to moisture change are obtained when subgrades are compacted wet at moisture contents above optimum — rather than when compacted dry, to be wetted later by natural forces.

Drainage— Where high grades are impractical, drain tile may be used to lower groundwater tables. The drain must be placed so that the groundwater level is lowered beyond the capillary range since capillary water cannot be effectively drained.

Where wet spots are encountered in the grade, due to seepage through a permeable strata underlaid by an impervious material, intercepting drains are used.

The backfill placed around and above pipe underdrains should be open-graded enough to permit rapid flow, but pores should not be large enough to be infiltrated by adjacent soils. Pipe backfill should meet filter criteria[5,45] (see filter design criteria on page 13) so that neither soil infiltration nor clogging of pipe openings will occur.

Nonfrost-Susceptible Cover— Layers of clean gravel and sand will reduce frost heave, but they are not required for this purpose if the less costly grading operations are properly done.

When a subbase layer is required to prevent mud-pumping, it also provides some protection against frost action. However, benefit from the use of thick subbase layers is somewhat diminished since coarse soils permit deeper frost penetration than do fine-grained soils with their higher moisture contents. The different thermal properties of the materials are largely due to differences in the in-place moisture contents.

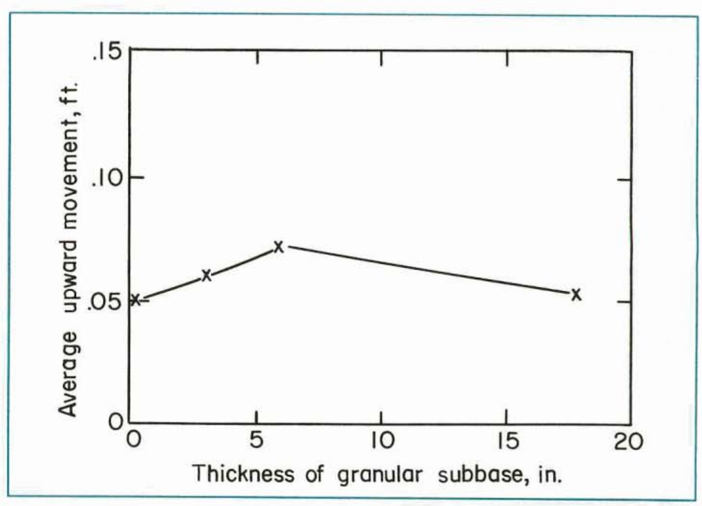

Fig. 9.— Effect of subbase thickness on frost heave.

An example of the effect of subbase thickness on frost heave is shown in Fig. 9 for a road in Minnesota.[46] Although the amount of heave is not great, the data show that it is not eliminated at subbase thicknesses up to 18 in. Usually, for greater amounts of heave, it would be expected that some reduction would be obtained with the use of nonfrost-susceptible subbases. These layers, however, are more effective in preventing loss in subgrade support on thaw, which is not a design consideration for concrete pavements.

Proper grade design, selective grading, and compaction control will produce uniform support and resistance to rapid moisture flow into the upper part of the subgrade. These are effective methods for preventing differential or excessive heaving. If a subbase layer is used, it is not necessary for it to be any thicker than the nominal depths needed to prevent mud-pumping.

Subbases

For concrete pavement design, performance experience and modern materials technology encourage the fullest and most economical use of all natural soils existing at the pavement site. Consequently, the engineer can analyze the design conditions and rationally decide if a subbase layer is essential or if less expensive alternatives can be used to meet the requirements for good performance.

The essential function of a subbase is to prevent mud-pumping of fine-grained soils. A subbase layer is mandatory under the combination of soils, water, and traffic that is conducive to mud-pumping. Such conditions frequently exist in the design situation for major, heavily travelled pavements. Conditions necessary for mud-pumping do not exist on low-traffic secondary roads, residential streets, and light-duty airports. For these, the use of a subbase layer is not economically justified, and the desired results can be obtained with the proper, less expensive subgrade preparation.

Also, when a subbase is required, it is not cost-effective to use a thick layer with the intention of increasing the structural capacity of the pavement. Most of the structural capacity is supplied by the slab itself.

Therefore, the economical functions of subbases may be classified as:

1. Primary (subbase required)
To prevent mud-pumping; the conditions that create a potential for mud-pumping are discussed in the next section.

2. Secondary (subbase optional)

a. To aid in controlling volume changes for severe conditions of high-volume-change subgrades.

b. To aid in reducing excessive differential frost heave.

c. To provide a drainage layer where needed.

d. To provide a more stable working platform for pavement construction.

Mud-Pumping. Studies and Surveys—

Mud-pumping is the forceful displacement of a mixture of soil and water that occurs under slab joints, cracks, and pavement edges. Mud-pumping can occur when concrete pavements are placed directly on fine-grained, plastic soils and erodible subbases. Continued, uncontrolled mud-pumping eventually leads to the displacement of enough soil so that uniformity of support is destroyed and slab ends are left unsupported.

Cooperative pumping studies by state agencies and the Portland Cement Association have shown that three factors are necessary for mud-pumping to occur:

1. A subgrade soil that will go into suspension.

2. Free water between pavement and subgrade or subbase.

3. Frequent passage of heavy axle loads.

In the AASHO Road Test,[42] on structurally underdesigned pavements, considerable pumping of the granular subbase material occurred. Thus, it is possible to pump granular materials with the excessive deflections caused by frequent loads on slabs of inadequate thickness. On normal in-service pavements subjected to mixed-weight traffic, pumping occurs only with fine-grained soils.

The performance of test sections with no subbase at the AASHO Road Test shows that adequately designed pavements without subbases are suitable for many city streets, county roads, light-traffic highways, and light-duty airports. Table 3 gives serviceability data and pumping factors for sections with no subbase versus 6-in. subbase, and also shows the benefit of subbase as a protection against pumping from very heavy loadings.

Subbase surveys* have been made on more than 2000 miles of concrete pavements in five states representing a wide range of climate, soils, and service conditions. These surveys show that:

* Cooperative studies by state highway departments and the Portland Cement Association.

Table 3— ***Performance and Heavy Pumping Factor for no-subbase and 6-in. subbase sections, 3rd level concrete design—all traffic loops***

Loop No.	Axle type	Axle load (kips)	Slab thick. (in.)	Subbase thick. (in.)	P at end of test	Repetitions at P=1.5 (in 1000's)	Heavy pumping factor [1]
2[2]	Single	2	5.0	0	4.1	—	0
				6	4.1	—	0
2	Single	6	5.0	0	4.1	—	0
				6	4.0	—	0
3[3]	Single	12	6.5	0	4.2	—	0
				6	4.1	—	0
4	Single	18	8.0	0	4.2	—	0
				6	4.4	—	0
5	Single	22.4	9.5	0	3.8	—	25
				6	3.7	—	15
6	Single	30	11.0	0	4.2	—	0
				6	4.2	—	0
3[3]	Tandem	24	6.5	0	4.0	—	0
				6	4.1	—	0
4	Tandem	32	8.0	0	2.4	—	100
				6	4.2	—	12
5	Tandem	40	9.5	0	—	658	907
				6	4.0	—	148
6	Tandem	48	11.0	0	—	907	925
				6	4.3	—	0

1 Pumping data obtained from AASHO Road Test Data System 4243, "Rigid Pavement Pumping Surveys"
2 Loop 2 data for Design 1 sections
3 Loops 3-6 data for Design 3 sections

1. Pavements designed to carry not more than 100 to 200 trucks* per day do not require subbases to prevent pumping damage.
2. Soils with less than 45 percent passing a No. 200 sieve and with a PI of 6 or less are suitable for moderate volumes of heavy truck traffic.
3. Subbases meeting AASHTO M155 effectively prevent mud-pumping in pavements carrying the greatest volumes of traffic.

The subbase studies included projects carrying as many as 700 axle loads per day of more than 18,000 lb and projects with tractor-semitrailer counts of 1000 to 2000 per day. AASHTO specification M155 to prevent pumping states:

> Granular material for use as subbase under concrete pavement may be composed of sand, sand-gravel, crushed stone, crushed or granulated slag, or combinations of these materials. The material shall meet the following requirements:
>
> | Maximum size: | Not more than one third the thickness of the subbase |
> |---|---|
> | Passing No. 200 sieve: | 15 percent max. |
> | Plasticity index: | 6 max. |
> | Liquid limit: | 25 max. |
>
> Note: Materials with a higher percentage passing No. 200 sieve or with a higher plasticity index than 6 or a higher liquid limit than 25 may be used, provided that a stabilization method found to be locally suitable is employed.

The material shall be graded suitably to permit compaction to such a density that a minimum increase in densification will occur after the pavement is in service.

Experience gained since these studies were conducted show that 15 percent passing the No. 200 sieve is excessive for pavements carrying high volumes of heavy truck traffic. (See next section on Untreated Subbases).

* Two-way traffic, not including panel and pickup trucks, and other four-tire single units.

Untreated Subbases—

A wide variety of materials and gradations has been used successfully for untreated subbases by different agencies. These include crushed stone, bank run sand-gravels, sands, soil-stabilized gravels, and local materials such as crushed mine waste, sand-shell mixtures, and slag.

The principal criterion is to limit the amount of fines passing a No. 200 sieve. Soft aggregates should be avoided because fines may be created due to the abrasion or crushing action of compaction equipment and construction traffic. Generally, aggregates having less than 50% loss in the Los Angeles abrasion test (AASHTO T96, ASTM C131) are satisfactory.

As a guide, Table 4 from AASHTO specification M147 shows typical subbase material gradations; ASTM specification D1241 is similar. When open-graded subbases* similar to Type A are used, precautions (filters are discussed later) may be necessary to prevent the intrusion of underlying fine-grained soils into the subbase.

* In this publication, the term "open-graded subbase" is not to be confused with the term "permeable subbase" discussed in a later section. As used here, the definitions of the terms are:
  - "Open-graded subbases" designate materials with a gradation similar to that shown as Grading A in Table 4. This is an older terminology that persists in the literature and in usage to some degree.
  - "Permeable subbases," (see discussion on pages 17 through 20) perhaps more commonly designated as open-graded, permeable subbases, have gained in popularity in recent years as a more effective drainage medium. They have much higher permeabilities and can drain water very quickly, which is not true of materials designated above as open-graded subbases.

Where local experience has shown it necessary to prevent damage by frost action, the materials should be used at or near the minimum fines content.

Gradation Control—

Although a wide variety of locally available materials has performed well as subbases for concrete pavements, the subbase for an individual project should have a reasonably constant gradation to allow compaction equipment to produce the uniform and stable support that is essential for good pavement performance. Abrupt changes in subbase gradation can be nearly as harmful as abrupt changes in subgrade soils.

AASHTO M147 divides various subbase materials into six separate gradations. Subbase for an individual project may be limited to one or two of the six gradations, or the contractor may be permitted to select a subbase source that complies with any one of the six gradations. In either case, the subbase for a particular project is kept within the limits of a single gradation.

However, while gradation control is improved, all six gradations permit a wide range in the percentage passing the various sieves. As a result, all gradations encompass subbases that can be either open graded and slightly-to-moderately permeable, or dense graded and relatively impermeable. Either type will perform satisfactorily if properly constructed, but a subbase with abrupt or uncontrolled variations between open and dense gradations can result in poor pavement performance.

Table 4— **Grading requirements for soil-aggregate materials**

Sieve Size	Percent Passing					
	Grading A	Grading B	Grading C	Grading D	Grading E	Grading F
2 in.	100	100	—	—	—	—
1 in.	—	75-95	100	100	100	100
3/8 in.	30-65	40-75	50-85	60-100	—	—
No. 4	25-55	30-60	35-65	50-85	55-100	70-100
No. 10	15-40	20-45	25-50	40-70	40-100	55-100
No. 40	8-20	15-30	15-30	25-45	20-50	30-70
No. 200	2-8	5-20	5-15	5-20	6-20	8-25

An effective way to ensure gradation control is to allow wide latitude in the selection of a subbase from gradation limits known to be satisfactory. Before work begins, the contractor should submit for approval a single gradation curve. Then the contractor would be required to furnish a subbase that did not vary from the approved material by more than about 5 percent, plus or minus.

Filter Design for Open-Graded Subbases*—
Where dense-graded subbases are specified, infiltration is not a problem. Open-graded subbases, however, can be subject to infiltration by fine-grained soils, and this can cause unsatisfactory pavement performance. The following criteria[45] to prevent infiltration of open-graded subbases are recommended:

1. The 15 percent size (D_{15}) of subbase should not be more than five times larger than the 85 percent size (D_{85}) of the filter.
2. The 50 percent size (D_{50}) of subbase should not be more than 25 times larger than the 50 percent size (D_{50}) of the filter.
3. The 15 percent size (D_{15}) of the filter should not be more than 5 times larger than the 85 percent size (D_{85}) of the subgrade soil.
4. The 50 percent size (D_{50}) of the filter should not be more than 25 times larger than the 50 percent size (D_{50}) of the subgrade soil.

(The D_X size means that x percent of the particles are smaller than this size.)

If the subbase is also used as cover for pipe underdrains, the 85 percent size of the subbase should be at least 1-1/2 to 2 times the size of the pipe opening.

Compaction—
Granular materials are subject to consolidation from the action of heavy traffic once the pavements are placed in service. To prevent a detrimental amount of consolidation, subbases must be compacted to very high densities. Research[47] at the Portland Cement Association laboratories simulating the action of truck traffic has documented the need for high subbase density for heavy-duty pavements. Typical results are shown in Fig. 10.

The research shows that as few as 50,000 load repetitions can produce excessive consolidation where densities are low and that 100 percent of AASHTO T99 density is the minimum necessary to prevent detrimental consolidation.

* see footnote on page 12.

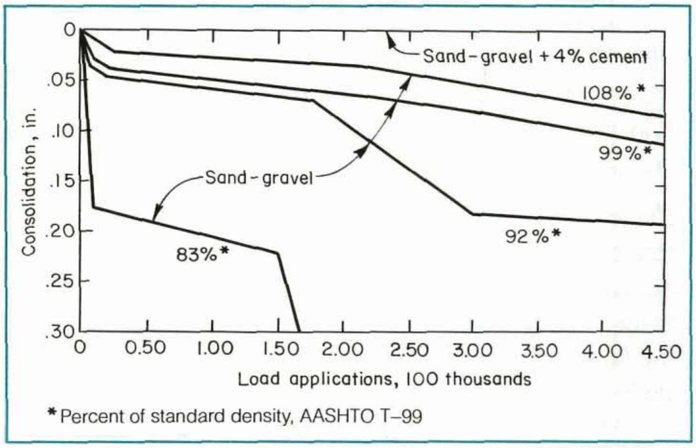

Fig. 10.— Subbase consolidation under repetitive loading.

The Corps of Engineers specifies 100 percent of AASHTO T180 density for subbases placed below airfield pavements. This is equivalent to about 105 to 108 percent of AASHTO T99 density. With today's compaction equipment, densities of this magnitude are feasible. They should be specified and rigidly enforced as an economical means of ensuring good pavement performance.

The standard laboratory tests do not provide adequate density controls for some cohesionless or nearly cohesionless subbases. In such cases an equivalent degree of compaction should be established by the tests for relative density of cohesionless soils, ASTM D4253 and D4254.

Consolidation of subbases under traffic is a matter of concern in another respect. As the thickness of the subbase is increased, the same continuing rate of consolidation from repetitive loads will produce even greater total amounts of consolidation. Fig. 11 shows the results of repetitive load tests on 4-, 6-, and 12-in. depths of subbase placed on a clay-loam subgrade and com-

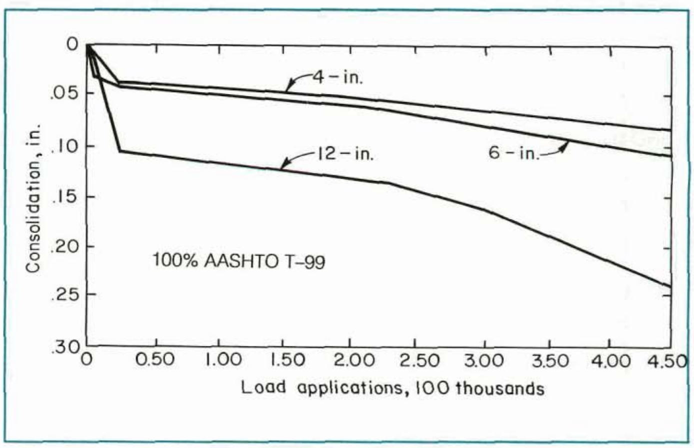

Figure 11.— Influence of subbase thickness on consolidation.

pacted to 100 percent AASHTO T99 density. After 450,000 load repetitions, there was more than twice as much consolidation on the 12-in. subbase as on the 4- or 6-in. subbases. The least amount of combined subgrade-subbase consolidation occurred on the 4-in. subbase.

Static load tests[4] were also performed at the PCA laboratories to determine how various types and depths of subbase affect the strains and deflections in full-scale slabs. For the loading position at transverse joint edges, these tests show only slight reductions in strains and deflections when subbase depths are greater than 4 to 6 in. Repetitive load tests[47] have demonstrated that the slight reductions in strain and deflection for 9- to 15-in. subbases are offset by the excessive consolidation of these thick subbases.

Thus, static and repetitive load tests furnish convincing support for these conclusions:

1. Subbases for concrete pavements should have a minimum of 100 percent AASHTO T99 density. On projects that will carry large volumes of heavy traffic, specified density should not be less than 105 percent of standard density or 98 to 100 percent of AASHTO T180 density.
2. The additional material and construction costs of providing thicker subbases is not justified. When subbase depths are increased beyond the 4 to 6 in. needed to prevent pumping, there is an increasing risk of poor pavement performance due to subbase consolidation from heavy traffic.

Thickness—

Since the primary purpose of a subbase is to prevent pumping, it is neither necessary nor economical to use thick subbases. Experimental projects have shown that a 3-in. depth of subbase will prevent mud-pumping under very heavy traffic. During the subbase surveys, slit-trench excavations made at pavement edges revealed that a subbase depth of 2 in. was preventing mud-pumping on projects that have carried heavy traffic for 10 years or more. Subbase depths of 4 to 6 in. are commonly specified for regular construction projects as a practical means of securing the minimum 2- to 3-in. depth needed to prevent pumping. Results of the subbase studies justify this practice.

For thick pavements at major airports, subbase thicknesses of 6 or 8 in., about a third to a half of the thickness of the concrete, are commonly used.

Cement-Treated Subbases and Lean Concrete Subbases—

The use of cement-treated subbases and, more recently, lean concrete subbases has been common practice for both highway and airport pavements in many areas. Among several reasons for their use, an important justification is the growing scarcity of aggregates that will meet specifications for pavement construction. Cement-treated and lean concrete subbases permit greater use of local materials, substandard aggregates, and recycled paving materials. This results in conservation of aggregates and savings in material and hauling costs.

Other benefits to be derived from the use of these treated subbases are:

1. Reducing pavement stresses and deflections due to vehicle loadings.
2. Providing firm support for slip-form paver or side forms.
3. Providing a stable working platform to expedite all construction operations and permit large daily production of concrete pavement with minimum down time for inclement weather.
4. Preventing subbase consolidation under traffic.
5. Providing improved load transfer at pavement joints.
6. Minimizing intrusion of hard granular particles into the bottom of pavement joints.
7. Providing a more erosion resistant subbase surface.
8. Constructing smooth pavements due to stable trackline for slipform pavers.

Cement-Treated Subbases—

In the family of cement bound materials (cement-treated subbase, lean concrete, and conventional concrete) cement-treated subbase contains the least amount of cement, usually about 4 or 5% cement by weight. Another difference is that cement-treated subbase mixtures are, like untreated subbases, of a much drier consistency and, therefore, are compacted with rollers.

Materials—

Granular materials in AASHTO Soil Classification Groups A-l, A-2-4, A-2-5, and A-3 are used for cement-treated subbases. They contain not more than 35 percent passing the No. 200 sieve, have a PI of 10 or less, and may be either pit-run or manufactured. Cement-treated subbases have been built with A-4 and A-5 soils in some nonfrost areas and are performing satisfactorily; generally, however, such soils are not recommended for subbases in frost areas or where large volumes of heavy truck traffic are expected. Use of A-6 and A-7 soils is not recommended. To permit accurate grading of the subbase, maximum size of material usually is limited to 1 in. and preferably to 3/4 in.

In many instances, dirty granular materials can be used that do not meet subbase specifications because of excess fines or plasticity. These inexpensive materials often require less cement than the cleaner, more expensive aggregates. The cement content for cement-treated subbase is based on standard laboratory wet-dry and freeze-thaw tests and PCA weight-loss criteria.[48] Other procedures that give an equivalent quality of material may be used.

Properties—
Cement-treated materials are ideally suited for subbases because of their resistance to erosion. Untreated subbases tend to erode beneath pavement joints as a result of traffic. In high-traffic volume situations, this often results in joint faulting and adversely affects the riding qualities of the pavement. This is especially significant where plain concrete slabs with undoweled joints are used.

The high-support values of cement-treated subbases are another desirable property. These values are measured by plate-load tests and expressed as the k value, Westergaard's modulus of subgrade reaction. It has been known for some time that plate-bearing tests on cement-treated subbases produce extremely high k values.

There has been some question as to whether these high k values reduce stresses in the overlying concrete slab. To determine this, full-size slabs were built on subgrades and subbases with known k values.[49] Fig. 12 shows the strains measured in the slabs under a 9000-lb load and the k values computed from these data. Computed k values are in close agreement with those determined by the plate-bearing tests made directly on subgrades and subbases. Hence, slab strains and corresponding stresses are significantly reduced by use of a cement-treated subbase.

Another area of research[50] of the PCA laboratories studied the effect of cement-treated subbases on load transfer across undoweled joints in plain concrete slabs. The results are shown in Fig. 13. As load applications were increased on the slab with untreated gravel subbase, effectiveness gradually decreased until it approached zero at 1 million loads. On the cement-treated subbase, the loss occurred at a much slower rate; even after 1 million loads, effectiveness remained at a level of over 50 percent.

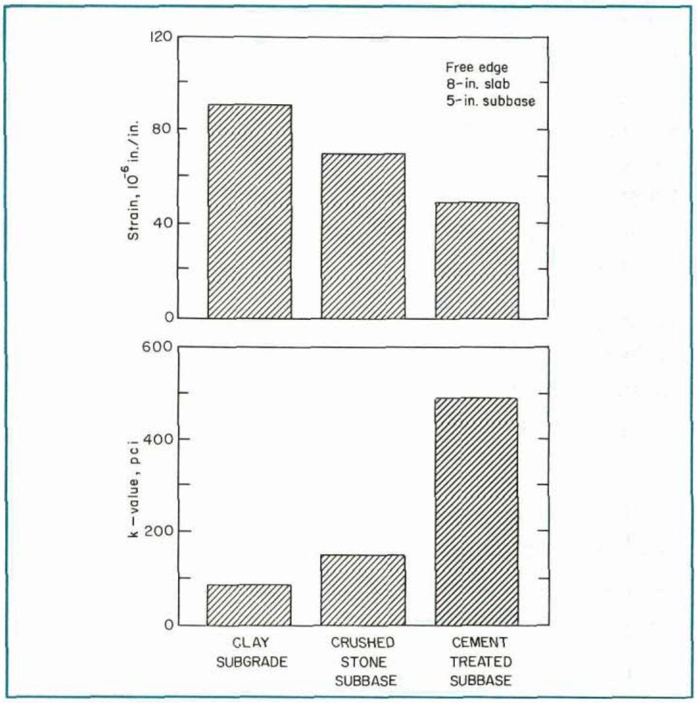

Figure 12.— Measured strains and computed k values, 9-kip plate load.

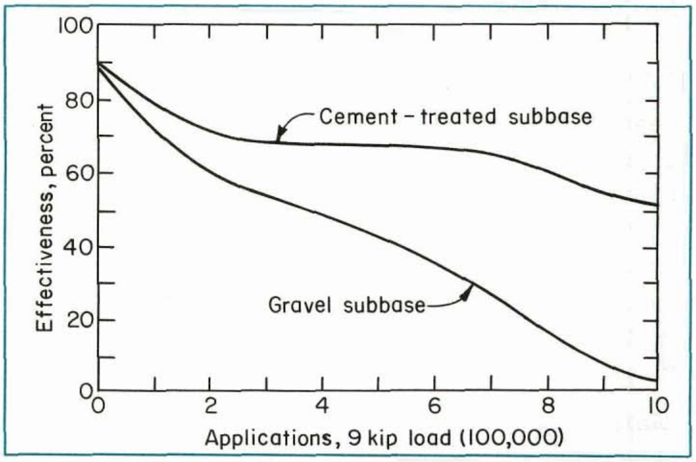

Fig. 13.— Effect of subbase type on load-transfer effectiveness.

These studies indicate that use of a cement-treated subbase will provide more effective load transfer over a longer period of time than will untreated subbase. As a result, use of the plain undoweled slab design with short joint spacings can sometimes be extended to pavements carrying greater traffic than the limit presently suggested.[51]

Construction—
Construction of cement-treated subbases can be accomplished by roadmix or central-plant methods. In road-mixing, the material can be processed in a blanket on the

subgrade. The proper amount of cement is placed with a cement spreader and mixing can be done either with multiple-pass mixers, where several passes are required for dry-mixing and moist-mixing materials, or with single-pass mixers that complete the entire process in one pass. When central mixing plants are used, the moist mixture is hauled to the roadway in dump trucks and spread by a mechanical spreader.

When granular material, cement, and water have been uniformly blended and spread to the proper depth and width, the mixture is compacted. The type of compaction equipment used depends on the gradation of the granular material selected.

The final step is to finish the cement-treated subbase to accurate grade and crown. Any surface moisture lost through evaporation during finishing operations must be replaced by a light fog spray.

After finishing operations are completed, the subbase is given a light fog spray of water and an application of a bituminous curing material. Detailed information on construction of cement-treated subbases will be found in Reference 52.

Lean Concrete Subbases—

Lean concrete subbase mixes are made with a greater amount of cement and water than cement-treated subbases, but they contain less cement than conventional concrete. Having the same appearance and consistency of conventional concrete, lean concrete is consolidated by vibration. Some engineers have adopted the term "econocrete" for such mixtures that utilize local aggregate materials.

Materials—

Lean concrete is designed for a specific application and environment and, in general, makes use of aggregates that do not necessarily meet quality standards for conventional concrete

Some of the restrictive requirements for conventional concrete relate to the performance characteristics of the pavement as an exposed surface, where lower cement contents and/or substandard aggregates may cause a slippery pavement. This is due to loss of surface texture or polishing of aggregate, lack of abrasion resistance, popouts, surface scaling, or other undesirable surface effects. However, some substandard aggregates are acceptable when used in lean concrete as a lower course in the pavement structure.

To reduce pavement costs and preserve high-quality aggregates, the U.S. Federal Highway Administration issued Notice N5080.34. It says: "The use of lower quality, locally available aggregates is encouraged for econocrete. The use of recycled pavement material serving as aggregate is encouraged. The limits to lower aggregate quality should be determined by the state, based on local experience, or by tests of econocrete designs."[53]

Data obtained from laboratory test programs and lean concrete construction projects[54] indicate that a rather wide range of aggregates may be used. Some of these aggregates are materials not processed to the degree that normal aggregates are. Most have more fine material passing the No. 100 and No. 200 sieves than is acceptable for normal concrete, but this is not necessarily objectionable for lean concrete because the extra fines supply needed workability. On several recycling projects, old concrete and asphalt pavements have been crushed and used as aggregates for lean concrete subbase.

The normal procedures and tests for concrete mix design are also followed for lean concrete subbase, with the following exceptions: a single aggregate is often used rather than a combination of coarse aggregate and fine aggregate stockpiled separately; the cement content is less than that for normal concrete and is selected on the basis of obtaining a strength level as discussed later; and a primary requirement is that the lean concrete subbase be workable, capable of adequate consolidation by vibration, and cohesive enough to resist excessive edge slumping when placed with a slipform paver. Another requirement is that the hardened lean concrete have the level of strength and durability appropriate for exposure conditions.

Workability may be enhanced by the existence of extra fines in the aggregate; higher than normal amounts of entrained air; addition of fly ash, water-reducing admixtures, or workability agents; or a combination of these.

Laboratory investigations and field installations indicate that the desirable properties of lean concrete used as a subbase course are achieved with cement factors in the range of 200 to 350 lb per cu yd, slumps from 1 to 3 in., average 28-day compressive strength between 750 and 1500 psi, and air contents equal to those recommended for normal concrete but somewhat greater (6% to 8% air for concrete made with 1- to 2-in. max. size aggregate) for freeze-thaw areas.

Additional information on materials and mix design is given in References 54 and 55.

Properties—

The results of several laboratory studies of strength and other properties of lean concrete at various cement contents are given in Reference 54. Fig. 14, showing compressive and flexural strength data from one of these studies, is fairly typical of the relationships. For the range of compressive strength recommended for lean concrete subbases (750 to 1500 psi), the static modulus of elasticity would usually fall in the range of 1.5 to 2.5 million psi. These properties represent a very strong and stiff material compared to all other subbase types.

The benefits of a cement-treated base (resistance to consolidation, high support (k) value, and effectiveness of

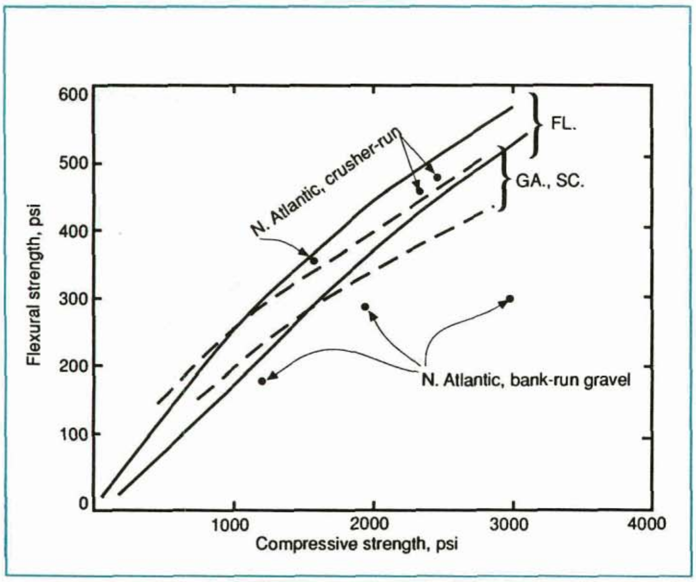

Fig. 14.— Flexural strength vs. compressive strength of lean concrete.

load transfer at joints) were discussed in a previous section. It is expected that lean concrete would have these benefits to at least the same degree, and probably to an even greater degree, because of its higher strength, modulus of elasticity, and resistance to erosion. Extensive studies[56] in France have shown the erosion potential of various materials: lean concrete is rated as "extremely erosion resistant," and cement-treated granular material with 5 percent cement is rated as "erosion resistant."

Construction—

Lean concrete subbases are constructed in essentially the same manner and with the same equipment as normal concrete pavements. The only differences are: (1) the jointing practice and (2) the treatment of the surface of the lean concrete subbase. In this regard, the following recommendations are made based on current experience.

Installation of joints in the lean concrete subbase are not considered necessary. Shrinkage cracks will develop but experience has shown, for the low strength recommended and the interlayer treatment discussed below, that the cracks will not usually reflect through the concrete surface.

The recommended interlayer treatment is to leave the surface of the lean concrete untextured to prevent a mechanical bond to the concrete surface and, further, to apply a wax base curing compound as a bondbreaker. One coat is applied immediately as a cure coat and another coat is applied shortly before the surfacing concrete is placed.

Examples of specifications for constructing lean concrete subbases are represented by References 57 and 58.

Permeable Subbases—

In recent years, several highway agencies have experimented with, or specified, drainable pavement systems for heavy-duty pavements where past experience has indicated the potential of pavement faulting and pumping. These systems consist of highly permeable subbase courses and edge drains that are designed to carry the water away rapidly.

Typical cross-sections are shown in Fig. 15. More detailed information on the design, material requirements, and construction practices is given in References 59, 60, and 61.

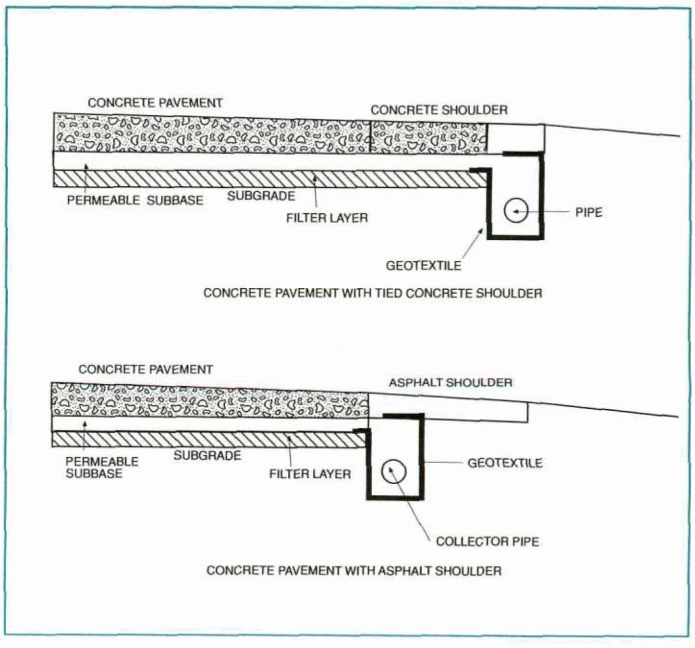

Fig. 15.— Typical permeable subbase sections.

Materials—

The permeable bases are made of crushed aggregates with a reduced amount of fines. The materials fall into two categories: untreated and treated. Treated subbases, which provide a stable construction platform, are bound with either cement (200 to 300 lb per cu yd) or asphalt (2 to 2.5 percent by weight). Various aggregate gradations are used by different agencies with AASHTO No. 57 and No. 67 stone being the most popular for treated subbases. Tables 5 and 6 show the gradations used by several agencies and the approximate coefficients of permeability.

Although materials as coarse and open-graded as AASHTO No. 57 stone are used, most agencies design the gradations to include more fines to obtain adequate stability for construction operations on top of untreated subbases. As a result, untreated permeable materials generally have a lower coefficient of permeability (500 - 3000 ft per day), whereas treated materials have a much higher coefficient (15,000 ft per day or higher).

The edge drains are backfilled with the same highly permeable material that is used for the subbase or a material with even higher permeability. Usually PVC pipe is used in the trench and for outlet laterals. A filter fabric lines the trench to prevent the intrusion of fine particles.

Most agencies prefer to use a layer of dense-graded aggregate placed between the subbase and subgrade to act as a filter course. However, a few agencies have used a filter fabric rather than an aggregate layer. Various filter design criteria for both aggregate and fabric are given in References 60 and 61.

Construction—

The permeable subbase material is usually placed and trimmed with a hopper-converted auto-trimmer or paver. Another method is to place the material by truck, spread with a blade, and cut to grade and cross-slope with an auto-trimmer.

Table 5— **Untreated permeable subbase gradations and permeabilities**

Sieve Size	Percent Passing						
	IA	KY	MI	MN	NJ	PA	WI
2-inch	—	—	—	—	—	100	—
1-1/2-inch	—	100	100	—	100	—	—
1-inch	100	95-100	—	100	95-100	—	100
3/4-inch	—	—	—	65-100	—	52-100	90-100
1/2-inch	—	25-60	0-90	—	60-80	—	—
3/8-inch	—	—	—	35-70	—	35-65	20-55
No. 4	—	0-10	0-8	20-45	40-55	8-40	0-10
No. 8	10-35	0-5	—	—	5-25	—	0-5
No. 10	—	—	—	8-25	—	—	—
No. 16	—	—	—	—	0-8	0-12	—
No. 30	—	—	—	—	—	0-8	—
No. 40	—	—	—	2-10	—	—	—
No. 50	0-15	—	—	—	0-5	—	—
No. 200	0-6	0-2	—	0-3	—	0-5	—
Coefficient of Permeability (ft per day)	500	20,000	1000	200	2000	1000	18,000

Table 6— Treated permeable subbase gradations and permeabilities

Sieve Size	Percent Passing				
	No. 57	California		Wis.	New Jersey
	AC/PC Stab.	AC Stab.	PC Stab.	PC Stab.	AC Stab.
1 1/2 in.	100	—	100	—	—
1 in.	95-100	100	86-100	—	100
3/4 in.	—	90-100	X± 22	90-100	95-100
1/2 in.	25-60	35-65	—	—	85-100
3/8 in.	—	20-45	X± 22	20-55	60-90
No. 4	0-10	0-10	0-18	0-10	15-25
No. 8	0-5	0-5	0-7	0-5	2-10
No. 10	—	—	—	0-5	—
No. 16	—	—	—	—	2-5
No. 200	0-2	0-2	—	—	*
Coefficient of permeability, ft/day	20,000	15,000	4,000	10,000	1,000

AC - Asphalt, PC - Portland cement.
"X" is the gradation that the contractor proposes to furnish for the specific sieve size.
* Add 2 percent mineral filler.

Compaction methods vary considerably among the different agencies that construct permeable subbases. The following are some of the most common techniques. For untreated and asphalt-treated materials, most agencies use 1 to 3 passes of a 4- to 10-ton steel-wheel roller in the static mode. Overrolling can cause degradation of the material with a resulting loss of permeability. Cement-treated materials are compacted in the same way or by use of vibrating screed or plates.

Cement-treated permeable subbases are cured by water misting several times a day or by covering with polyethylene sheets for 3 to 5 days. Normal concrete curing compounds are not used because the very coarse surface texture cannot be effectively sealed, and it is not desirable to do so.

For pavements to be built as a crowned section, edge drains are installed along both the inner and outer pavement edge. This shortens the drainage path and lessons the time for the permeable subbase to drain. However, for pavement lanes built as an uncrowned section, only one edge drain is installed at the low side; this is considerably less expensive.

In some cases, the inside edge of the trench has been located directly below the pavement-shoulder joint; however, the preferred method is to position the trench 2 or 3 ft farther out to avoid settlement problems or crushing of the collector pipe beneath construction equipment. In some cases, the permeable subbase is extended under the shoulder with the edge drain placed at the outside shoulder edge.

Daylighting of the subbase to the ditch slope hasn't worked well because slopes become overgrown with vegetation and plugged with roadside debris. Therefore, it is recommended that lateral outlet pipes be installed; spacings are not to exceed 300 to 500 ft to ensure rapid drainage.

The thickness of the permeable subbase has varied from 3 to 6 in. with 4 in. being the most common. The consensus is that 4 in. will provide adequate drainage capacity.

The 4-in. thickness of permeable subbases is considered appropriate for highway pavements. For airport pavements and other pavements where a large expanse of area is to be drained, an adequate design may require a thicker layer of permeable subbase because of the longer drainage path. More information on drainage design and criteria is given in Reference 61 and in textbooks on the topic.

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